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RESEARCH MEMORANDUM

INVESTIGATION OF THE EFFECT OF INDENTATION ON AN M-PLAN-FORM-WING—BODY COMBINATION AT TRANSONIC SPEEDS

By Donald L. Loving

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INVESTIGATION OF THE EFFECT OF INDENTATION ON AN M-PLAN-FORM-WING—BODY COMBINATION AT TRANSONIC SPEEDS

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SUMMARY

The effect of body indentation on the aerodynamic characteristics of an M-plan-form-wing—body combination has been investigated for angles of attack from 0° to 12° at Mach numbers from 0.80 to 1.13 in the Langley 8-foot transonic tunnel. The Reynolds number of the investigation varied from 1.60×10^{6} to 1.66×10^{6}. The M-wing with 45° sweep angles was tested on a plain body and a body with an indentation that was 65 percent of that required for a Mach number of 1.0. A similar 45° sweptback wing was tested on a plain body to furnish basic comparison information.

The drag-coefficient level and drag rise at all test lift coefficients for the M-wing on the basic body generally were higher than those for the sweptback wing on the same body, especially in the transonic speed range. The lift-curve slope for the M-wing on the basic body was slightly higher than for the comparable sweptback-wing—body combination. The maximum lift-drag ratio, however, for the M-wing—basic-body combination was less than for the sweptback-wing—basic-body combination. An unstable trend at moderate lift coefficients associated with the swept-back wing at low speeds was alleviated and pitch-up at Mach numbers of 0.96 and above was nonexistent for the M-wing.

The use of a body having a 65-percent $M = 1.0$ indentation in combination with the M-wing significantly diminished the drag penalty of the configuration, especially at a Mach number of 1.0 where the zero lift-drag rise was reduced approximately 50 percent. The indentation also was responsible for a slight increase in the lift-curve slope and a further improvement in the stability characteristics of the M-wing combination.

If comparisons are made for similar M- and sweptback wings, having the same tip deflection for the same load, mounted on fully indented bodies, it is estimated on the basis of experimental data obtained in this and other related investigations that the M-wing configuration probably will afford a substantial improvement in stability characteristics over those for the sweptback-wing configuration, without being associated with a severe drag penalty.

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INTRODUCTION

The use of an M-plan-form wing composed of a sweptforward inboard section and a sweptback outboard section has been suggested as a possible means for avoiding some of the difficulties encountered with conventionally swept wings. Previous investigations of this type of wing have indicated that for equal loads an M-wing has less twist and deflection and generally better stability characteristics (refs. 1 to 3) than a sweptback wing of the same thickness, aspect ratio, and taper. To offset these appealing characteristics, the M-wing has a greater drag at transonic speeds than does a comparable sweptback wing (refs. 1 and 2). With the development of the axial-area-distribution concept (ref. 4) the possibility became evident that part of the reason for the high drag rise for the M-wing at transonic speeds was the relatively poor axial distribution of cross-sectional area, because the whole area of the wing was confined to a relatively small region longitudinally. It was believed that, if the area distribution was made more favorable by indenting the body in accordance with the principles set forth in reference 4, the M-wing—body combination might have a much lower transonic drag rise than the wing on the plain body and would become competitive again with other wings having inherently low transonic drag rise. This possibility appeared especially promising if a thinner M-wing having the same deflection for a given load as a thicker sweptback wing were used in combination with the indented body.

In order to obtain an indication of the characteristics of the M-wing with an indented body, an investigation has been conducted at Mach numbers from 0.80 to 1.13 in the Langley 8-foot transonic tunnel on an M-wing and on a sweptback wing having an aspect ratio of 6, a taper ratio of 0.6, NACA 65A009 sections parallel to the airstream and with the quarter-chord lines having sweep angles of 45°. The body contour used with the M-wing had an indentation which was 65 percent of the full indentation specified by the transonic area rule. This limitation was imposed by the basic structure of the test model.

SYMBOLS

b	wing span
c	wing chord measured parallel to plane of symmetry
$\bar{c}$	mean aerodynamic chord measured parallel to plane of symmetry, $\frac{2}{S}\int_0^{b/2} c^2 dy$

M	Mach number
q	free-stream dynamic pressure, $\frac{1}{2}\rho V^2$
r	body radius
R	Reynolds number, $\rho V\bar{c}/\mu$
S	total wing area
V	velocity in undisturbed stream
x	body station, distance from nose of body
α	angle of attack of body center line
ρ	mass density in undisturbed stream
μ	coefficient of viscosity in undisturbed stream
C_L	lift coefficient, Lift/qS
$\left(\frac{dC_L}{d\alpha}\right)_{av}$	lift-curve slope, averaged over a lift-coefficient range from 0 to 0.4
C_D	drag coefficient, Drag/qS
$(L/D)_{max}$	maximum lift-drag ratio
C_m	pitching-moment coefficient about 25 percent mean-aerodynamic-chord position, Pitching moment/$qS\bar{c}$
C_m'	pitching-moment coefficient about an assumed center-of-gravity location which gives each wing-body combination the same moment-curve slope of -0.05 at $M = 0.8$

APPARATUS

Tunnel.- The investigation was conducted in the Langley 8-foot transonic tunnel. In this facility, the slotted-test-section Mach number can be varied continuously from about 0.2 to 1.14. The details of the test section are presented in figure 1. The location of the models discussed in this report are indicated in terms of the distance from the test-section slot origin to the nose of the body.

Models.- Two wings were used in this investigation. One had an M-plan-form shape and is referred to as the M-wing. The other wing was a plane conventional sweptback wing from which the composite plan form was derived. Both wings had an aspect ratio of 6, a taper ratio of 0.6, and NACA 65A009 airfoil sections parallel to the airstream. The quarter-chord line of the inboard 50-percent semispan of the M-wing was sweptforward 45°. The quarter-chord line of the outboard half of the semispan was swept back 45°. The sweep angle of the quarter-chord line of the sweptback wing was 45°. The M-wing had a steel core with a tin-bismuth covering and a brass trailing edge. The sweptback wing was made entirely of aluminum alloy. The stiffnesses of the two wings were sufficiently the same so as not to introduce any aeroelastic effects.

The plain body, which is referred to as the basic body, was the same as that used in the investigations which have been reported in references 5 and 6. It had a curved forebody, a 4-inch cylindrical midsection, and a curved afterbody profile. The M-wing and the sweptback wing were tested on this basic body.

In order to investigate any type of body shape in the region of the wing, the outer portion of the body between 22.5 and 36.9 inches to the rear of the model nose was made of detachable, wood-impregnated plastic. The M-wing was tested on the body with an indented contour (indentation) fitted into this region. As designed and constructed, the indentation was 65 percent as deep as that required for a $M = 1.0$ indentation for this configuration. This limitation was imposed by the basic structure of the variable-geometry test body. Indenting the body for the $M = 1.0$ condition, as specified by the area rule, would have resulted in an equivalent-body area distribution for the M-wing—body combination which would be the same as the axial distribution of area for the basic body alone. The body ordinates are presented in table I. Dimensional details for the wing-body combinations tested are presented in figure 2. Axial distributions of cross-sectional area for the various configurations are presented in figure 3.

The models were mounted on an internal strain-gage balance and were sting supported in the tunnel in the manner shown in figure 1. An attempt was made to maintain the models aerodynamically smooth throughout the investigation. Photographs of the M-wing mounted on the indented body are presented as figures 4(a) and 4(b).

MEASUREMENTS AND ACCURACY

The tests were made for a Mach number range from 0.80 to 1.13 at angles of attack of 0°, 2°, 4°, 6°, 9°, and 12°. The average Reynolds number varied between 1.60×10^6 and 1.66×10^6 for these tests as shown in figure 5.

Lift, drag, and pitching moment were determined by means of the internal strain-gage balance. The coefficients of these forces and moment are estimated to be accurate within the following limits: C_L, ± 0.01; C_D, ± 0.001; C_m, ± 0.003.

Model angle of attack was measured by means of a fixed-pendulum, strain-gage unit mounted in the nose of the body. Angles of attack are estimated to be accurate within $\pm 0.1^\circ$.

All data presented are essentially free of the effects of wall-reflected disturbances. The results have been adjusted to the condition of stream static pressure on the base of the body.

RESULTS AND DISCUSSION

The basic aerodynamic data for each configuration are given for a range of Mach number from 0.80 to 1.13 in figure 6. Analysis data are shown in figures 7 to 10.

Drag characteristics.- As indicated in figures 6(a) and 7 the drag coefficients for the M-wing on the basic body were higher than those for a similar sweptback wing on the same body at the tested lift conditions, especially at transonic speeds. Previous drag comparisons between M-wings and similar sweptback wings have shown the same characteristics (refs. 1 and 2). The use of a 65-percent $M = 1.0$ body indentation resulted in a considerably lower drag for the M-wing—indented-body combination throughout the lift range of the test than for the M-wing—basic-body combination. For lift coefficients from 0 to 0.4, as shown in figure 7, favorable reductions in drag rise for the M-wing due to indentation were obtained throughout the transonic speed range. The largest decrease in drag rise (approximately 50 percent) occurred for the zero lift condition at a Mach number of 1.0.

The maximum lift-drag ratio for the M-wing on the basic body was lower throughout the test Mach number range than for the sweptback wing on the same body, figure 8. The lower $(L/D)_{max}$ for the M-wing is partially a result of high drag due to lift associated with separation over the wing at the wing-body juncture. This characteristic has been shown previously in reference 7 for a sweptforward wing. The use of the 65-percent $M = 1.0$ indentation increased the maximum measured lift-drag ratio for the M-wing above that for the same wing on the basic body.

The difference at low speeds is not much greater than the experimental accuracy. The difference at Mach numbers in the vicinity of 1.0, however, is real and amounts to a significant gain.

The lift coefficient at which $(L/D)_{max}$ occurs varied from approximately 0.25 to 0.4 with increase in Mach number for the configurations tested. The most rapid change occurred between Mach numbers of 0.93 and 1.00. The change was less abrupt for the M-wing on the indented body.

Lift characteristics.- The lift-curve slopes presented in figure 9 were averaged for a lift-coefficient range from 0 to 0.4. Generally, the lift-curve slope of the M-wing on the basic body was greater than for the sweptback wing on the same body, except at Mach numbers near 0.93. This characteristic near $M = 0.93$ has been noted previously (ref. 2). Indenting the body had a tendency to increase the lift-curve slope of the M-wing especially in the Mach number range from 0.90 to 1.10.

Pitching-moment characteristics.- Any comparison of the pitching-moment characteristics depends on the location of the center of gravity. For the analysis of the present investigation, the center of gravity chosen for the basic pitching-moment data shown in figure 6(c) was shifted to give the same slope (-0.05) of the moment curve near zero lift at a Mach number of 0.80 for all three configurations tested. These adjusted data are presented in figure 10. The data indicate several marked differences in the pitching-moment characteristics of the configurations investigated. In general, the M-wing configurations exhibited a more stable trend than that for the sweptback-wing configuration with the degree of stability being slightly greater for the M-wing on the indented body. The early irregularity in the pitching-moment curves for the sweptback wing (fig. 10) was not noticed for a similar 6-percent-thick sweptback wing (ref. 8). The irregularity is believed due to separation associated with the thicker wing sections used in the present investigation. The most significant differences in pitching-moment characteristics between the M-wing and sweptback-wing configurations were the marked change toward instability exhibited by the sweptback-wing configuration at relatively low lift coefficients and the apparent elimination of pitch-up (a nonlinearity of the pitching-moment-coefficient curve indicating severe instability) by the M-wing configurations at Mach numbers of 0.96 and above. Even though the pitch-up was not eliminated at Mach numbers below 0.96 it was delayed to such an extent that the stability characteristics of the M- and sweptback-wing configurations were entirely different. The use of indentation improved the stability characteristics of the M-wing configuration by alleviating slight nonlinearities in the curves at moderate lift coefficients for Mach numbers from 0.90 to 0.96.

Estimated results.- If the torsional stiffness of the wings is considered, an interesting comparison can be made of estimates based on the experimental results of this and other related investigations. Unpublished static load tests have indicated that a 7-percent-thick M-wing develops approximately the same amount of tip deflection as a 9-percent-thick sweptback wing when subjected to the same load. The comparison which follows has been made for two such wings in combination with fully indented bodies. The estimated value of the drag rise for zero lift at a Mach number of 1.0 for the 7-percent-thick M-wing on a fully indented body has been determined in the following manner:

$$\Delta C_{D_{M,7,100}} = \Delta C_{D_{body}} + \left(\frac{7}{9}\right)^2 \left[\left(\Delta C_{D_{M,9,0}} - \Delta C_{D_{body}}\right) - \frac{100}{75}\left(\Delta C_{D_{M,9,0}} - \Delta C_{D_{M,9,65}}\right)\right]$$

where

Δ	increment of quantity between Mach number of 0.8 and Mach number of 1.0
$\Delta C_{D_{M,7,100}}$	drag-coefficient increment for 7-percent-thick M-wing on 100-percent-indented body
$\Delta C_{D_{body}}$	drag-coefficient increment for basic body alone
$\Delta C_{D_{M,9,0}}$	drag-coefficient increment for 9-percent-thick M-wing on basic body (0-percent indentation)
$\Delta C_{D_{M,9,65}}$	drag-coefficient increment for 9-percent-thick M-wing on 65-percent-indented body

The foregoing relation was derived from the assumption that a 65-percent indentation should be approximately 75 percent as effective as a full (100 percent) indentation. This assumption was suggested by the unpublished results of a transonic investigation of several types of body indentations.

A second assumption involved in the foregoing formula is that the difference between the drag coefficient increment of a given fully indented wing-body configuration and that of the basic body of revolution varies as the square of the wing thickness ratio.

The value of $\Delta C_{D_{body}}$ is found in reference 6 to be approximately 0.0015. From figure 7 the values of $\Delta C_{D_{M,9,0}}$ and $\Delta C_{D_{M,9,65}}$ are found to be 0.0226 and 0.0107, respectively. Thus, $\Delta C_{D_{M,7,100}}$ is calculated as 0.0047.

The drag-coefficient increment for the 9-percent-thick conventionally sweptback-wing—fully-indented-body configuration may be estimated as follows:

$$\Delta C_{D_{S,9,100}} = \Delta C_{D_{body}} + (1 - 0.9)\left(\Delta C_{D_{S,9,0}} - \Delta C_{D_{body}}\right)$$

where

$\Delta C_{D_{S,9,100}}$ drag-coefficient increment of 9-percent-thick sweptback wing on 100-percent-indented body

$\Delta C_{D_{S,9,0}}$ drag-coefficient increment of 7-percent-thick sweptback wing on basic body (0-percent indentation)

The foregoing formula is based on the assumption, derived from reference 6, that the incremental drag rise $\left(\Delta C_{D_{S,9,100}} - \Delta C_{D_{S,9,0}}\right)$ is reduced 90 percent by 100-percent indentation. From figure 7 $\Delta C_{D_{S,9,0}}$ is found to be 0.0145. The value of $\Delta C_{D_{S,9,100}}$ is then 0.0028. These estimates indicate that the 7-percent-thick M-wing and 9-percent-thick sweptback-wing configurations have comparable low drag-rise characteristics.

The results of the present investigation also indicate that full indentation for the M-wing might increase the lift-curve slope slightly. It is believed that a reduction in M-wing thickness from 9 to 7 percent will not affect the lift-curve slope appreciably. The results of reference 9 indicate that full indentation will not have any effect on the lift-curve slope of the sweptback wing.

Mounting the M-wing or sweptback wing on fully indented bodies and decreasing the M-wing thickness slightly will not alter significantly the pitch-up characteristics of these configurations.

It may be seen now that for such configurations as the 7-percent-thick M-wing and the 9-percent-thick sweptback wing on fully indented bodies the M-wing combination probably would afford a substantial improvement in stability characteristics compared with those of the sweptback-wing configuration without being associated with a severe drag penalty.

CONCLUSIONS

The following conclusions have been made as a result of an investigation to determine the effect of indentation on the aerodynamic characteristics of an M-plan-form-wing—body combination:

1. The drag-coefficient level and transonic drag rise at all the test lift coefficients for the M-wing on the basic body generally were higher than those for the sweptback wing on the same body.

2. The drag rise of the M-wing—body combination was significantly reduced by an indentation which was 65 percent of that specified by the transonic area rule. At zero lift and a Mach number of 1.0, the drag rise was reduced approximately 50 percent.

3. The lift-curve slope for the M-wing on the basic body was generally slightly higher than for the sweptback wing on the same body. Indenting the body for the M-wing resulted in an additional slight increase in the lift-curve slope.

4. The stability characteristics of the M-wing on the basic body were superior to those for the sweptback wing on the same body. Pitch-up associated with the sweptback wing was nonexistent for the M-wing at Mach numbers of 0.96 and above. Indenting the body further improved the stability characteristics of the M-wing by eliminating nonlinearities at moderate lift coefficients.

5. If estimated results are used to compare similar M- (7-percent-thick) and sweptback (9-percent-thick) wings, having the same tip deflection for the same load, mounted on fully indented bodies, it can be shown that the M-wing configuration probably would afford a substantial improvement in stability characteristics over those for the sweptback-wing configuration, without being associated with a severe drag penalty.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 4, 1954.

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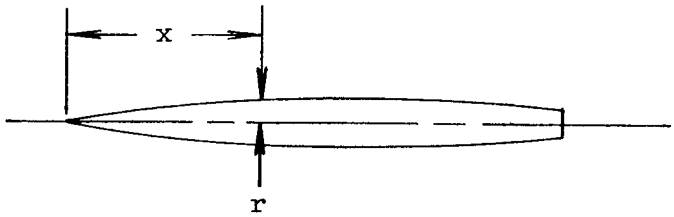
TABLE I.- BODY ORDINATES



Forebody ordinates, all configurations	
Body station, x, in.	Body radius, r, in.
0	0
.225	.104
.338	.134
.563	.193
1.125	.325
2.250	.542
3.375	.726
4.500	.887
6.750	1.167
9.000	1.391
11.250	1.559
13.500	1.683
15.750	1.770
18.000	1.828
20.250	1.864
22.500	1.875

TABLE I.- BODY ORDINATES - Concluded

Afterbody ordinates			
Basic body		65-percent-indented body	
Body station, x, in.	Body radius, r, in.	Body station, x, in.	Body radius, r, in.
22.500	1.875	22.50	1.875
23.000	1.875	23.00	1.847
23.692	1.875	23.50	1.810
24.192	1.875	24.00	1.762
24.692	1.875	24.50	1.707
25.192	1.875	25.00	1.647
25.692	1.875	25.50	1.592
26.192	1.875	26.00	1.545
26.692	1.872	26.50	1.513
27.192	1.871	27.00	1.494
27.692	1.868	27.50	1.483
28.192	1.866	28.00	1.480
28.692	1.862	28.50	1.486
29.192	1.856	29.00	1.502
29.692	1.849	29.50	1.528
30.192	1.839	30.00	1.562
30.692	1.825	30.50	1.603
31.192	1.808	31.00	1.644
31.692	1.789	31.50	1.678
32.192	1.768	32.00	1.705
32.692	1.745	32.50	1.717
33.192	1.720	33.00	1.714
33.692	1.694	33.50	1.702
34.192	1.667	34.00	1.678
34.692	1.638	34.50	1.650
35.192	1.608	35.00	1.618
35.692	1.570	35.50	1.585
36.192	1.531	36.00	1.545
36.692	1.486	36.50	1.505
36.900	1.467	36.90	1.467
37.50	1.408	37.50	1.408
38.00	1.355	38.00	1.355
38.50	1.298	38.50	1.298
39.00	1.235	39.00	1.235
39.50	1.167	39.50	1.167
40.00	1.100	40.00	1.100
40.50	1.030	40.50	1.030
41.25	.937	41.25	.937

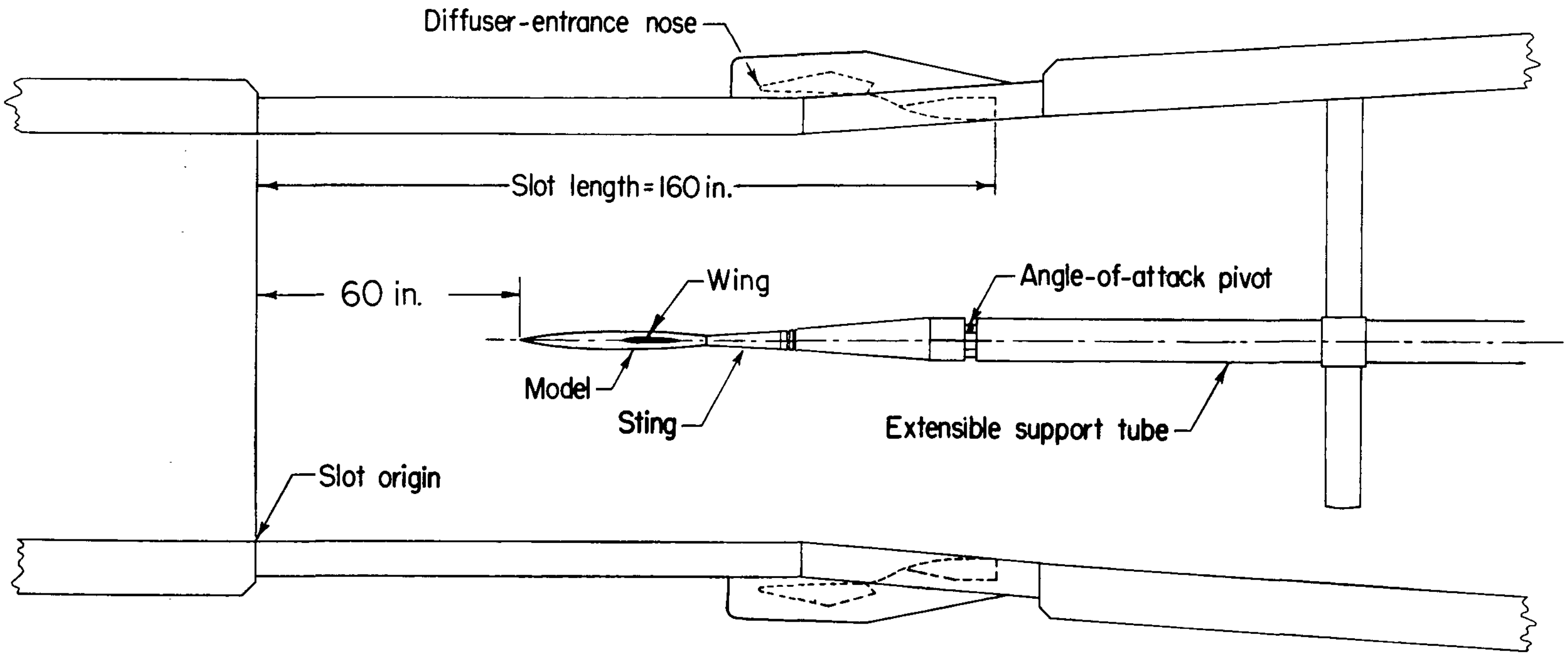


Figure 1.- Details of test section and location of model in Langley 8-foot transonic tunnel.

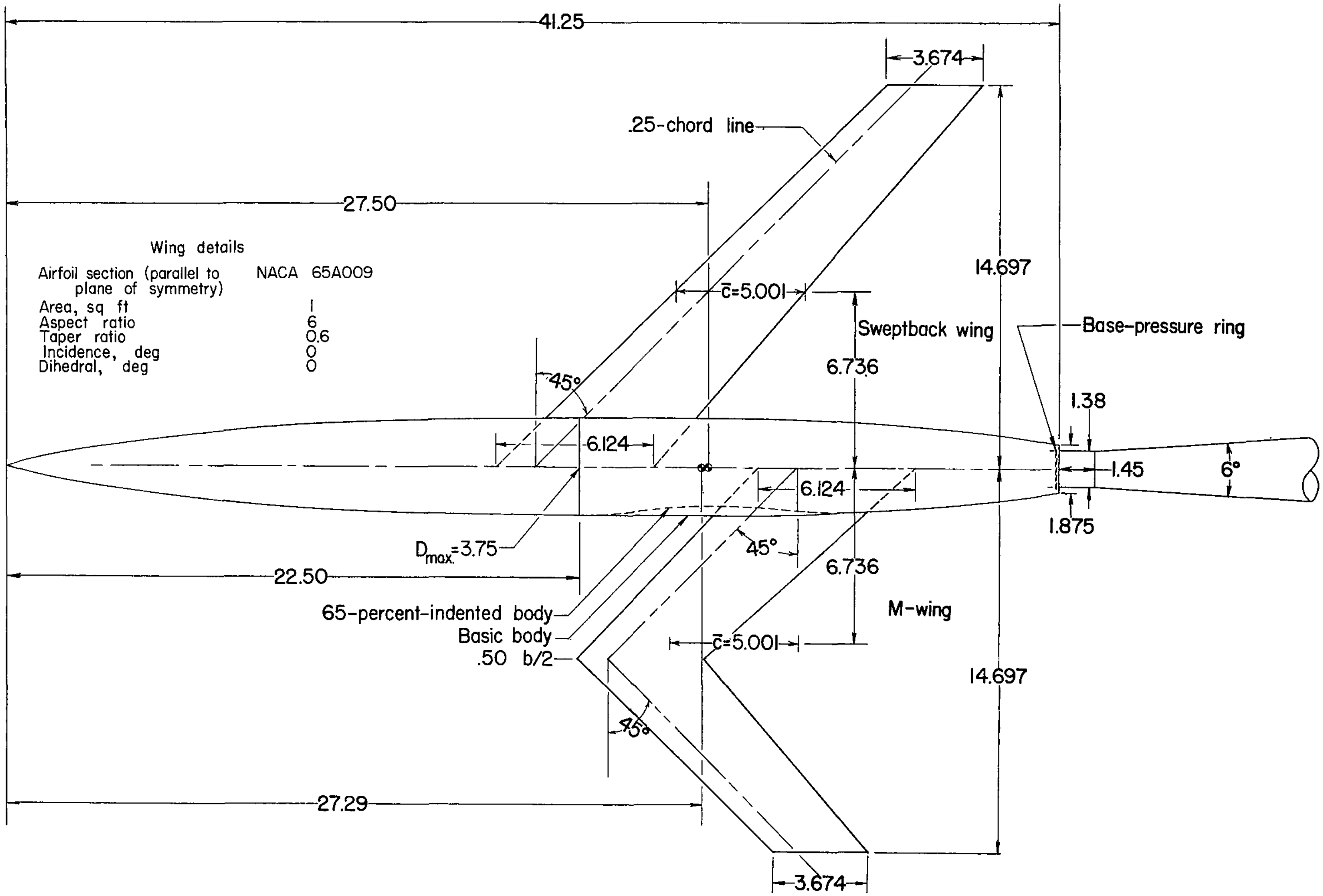


Figure 2.- General arrangement of test models. (All dimensions are in inches except as otherwise noted.)

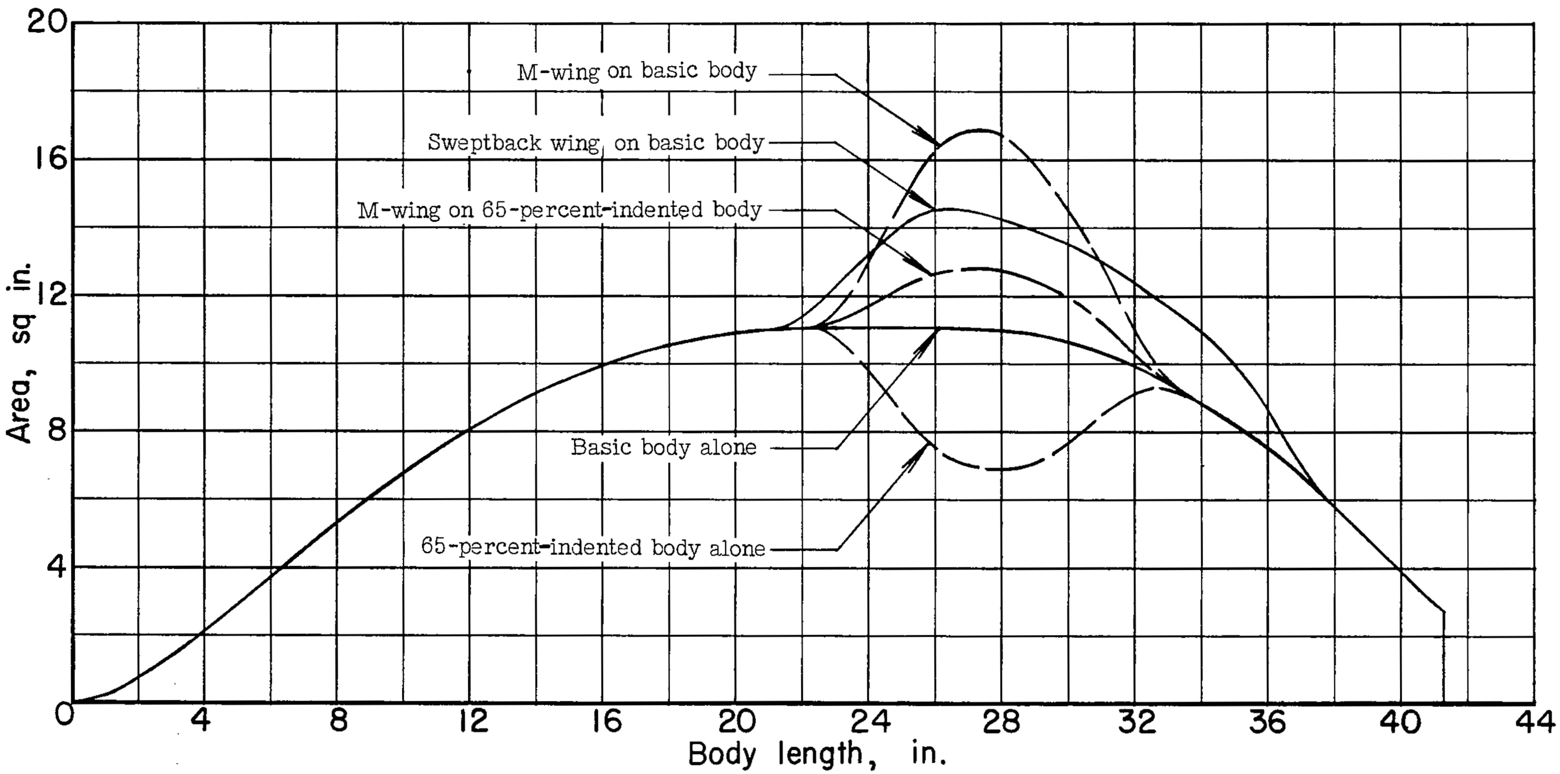
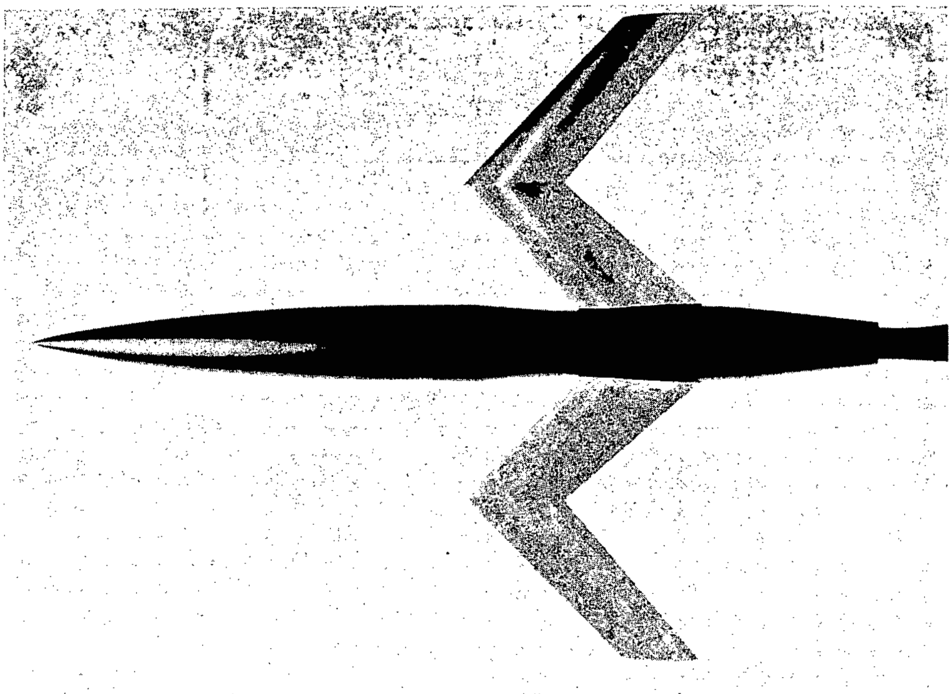


Figure 3.- Axial distribution of cross-sectional area of the configurations investigated.



L-83251.1

(a) Plan view.

L-83248.1

(b) Three-quarter rear view.

Figure 4.- Photographs of the M-wing mounted on the 65-percent-indented body.

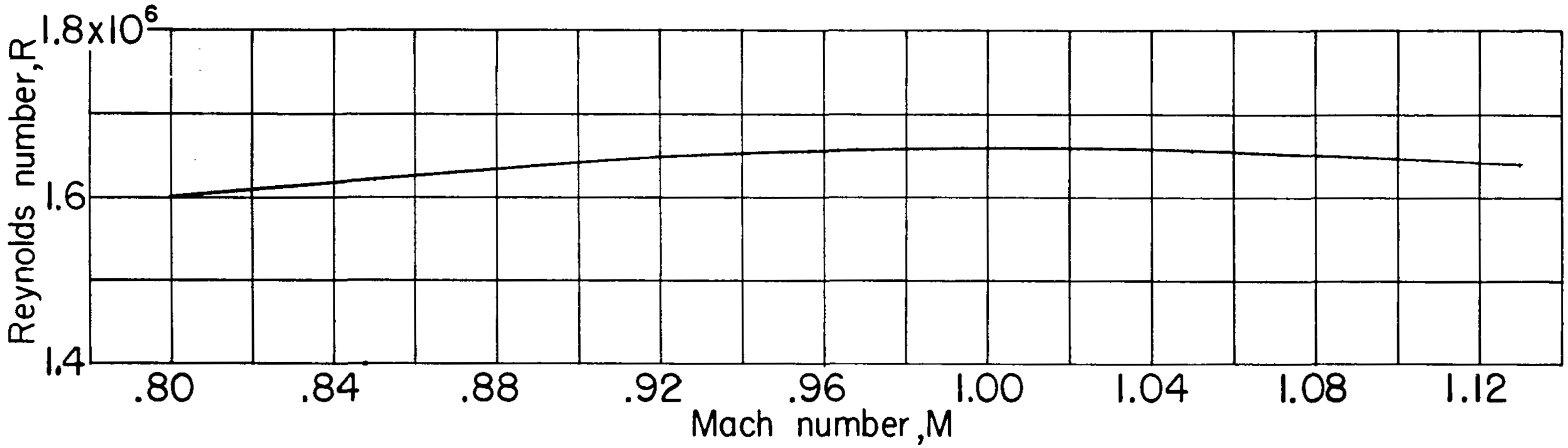


Figure 5.- Variation with Mach number of average test Reynolds number based on mean aerodynamic chord of 5.001 inches.

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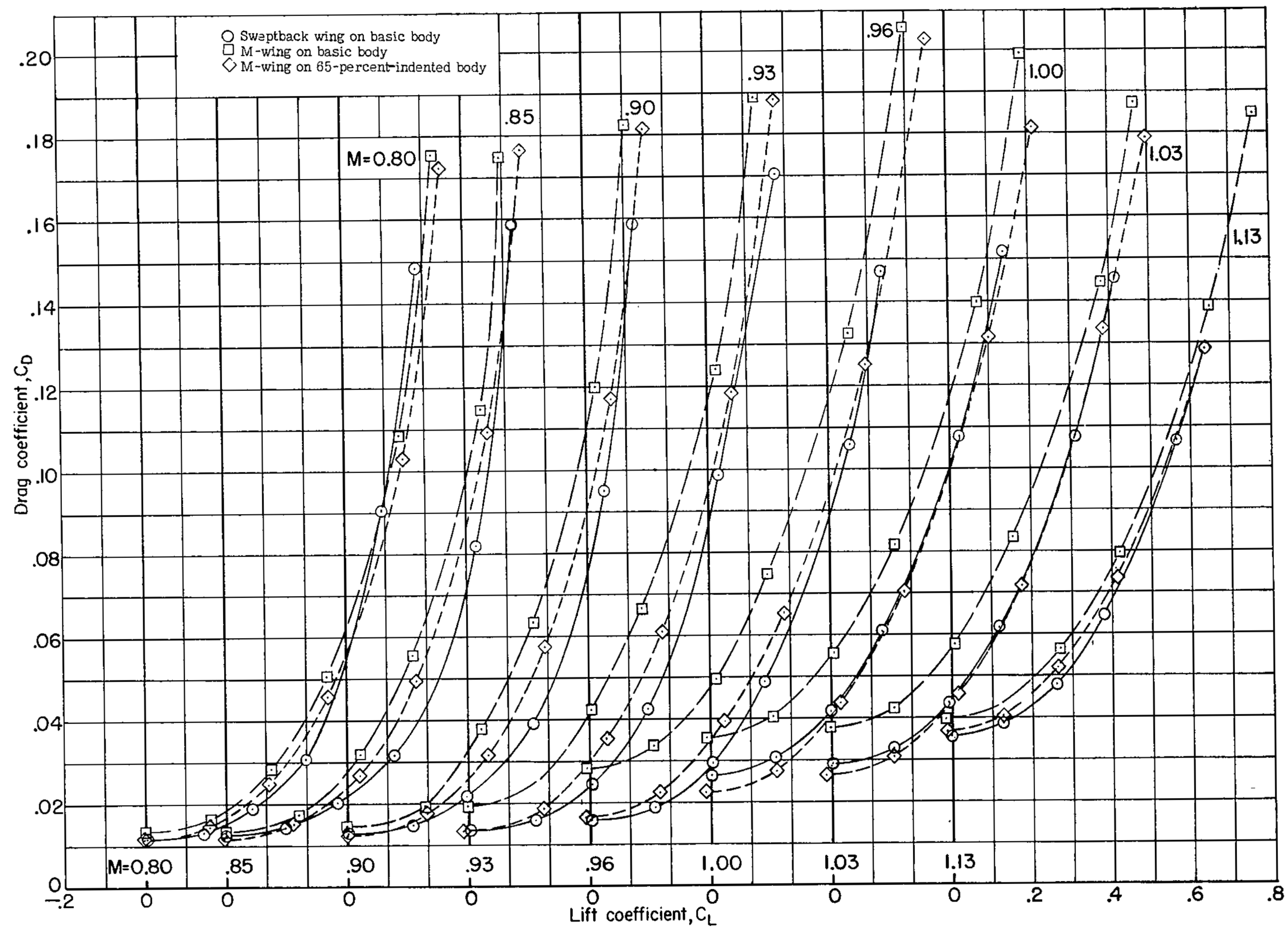

(a) C_D against C_L.

Figure 6.- Aerodynamic characteristics of wing-body combinations investigated.

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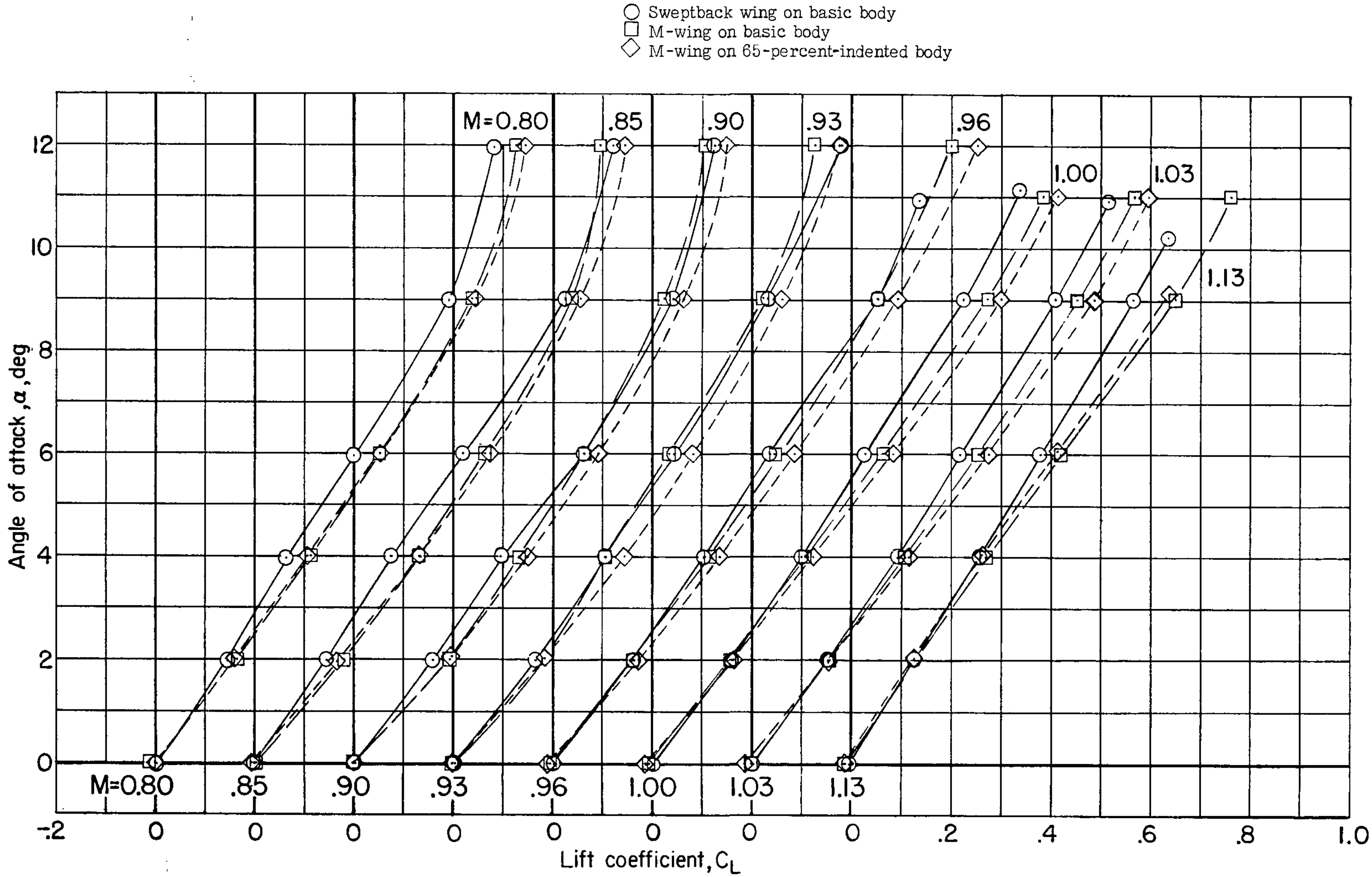
[redacted]



(b) α against C_L.

Figure 6.- Continued.

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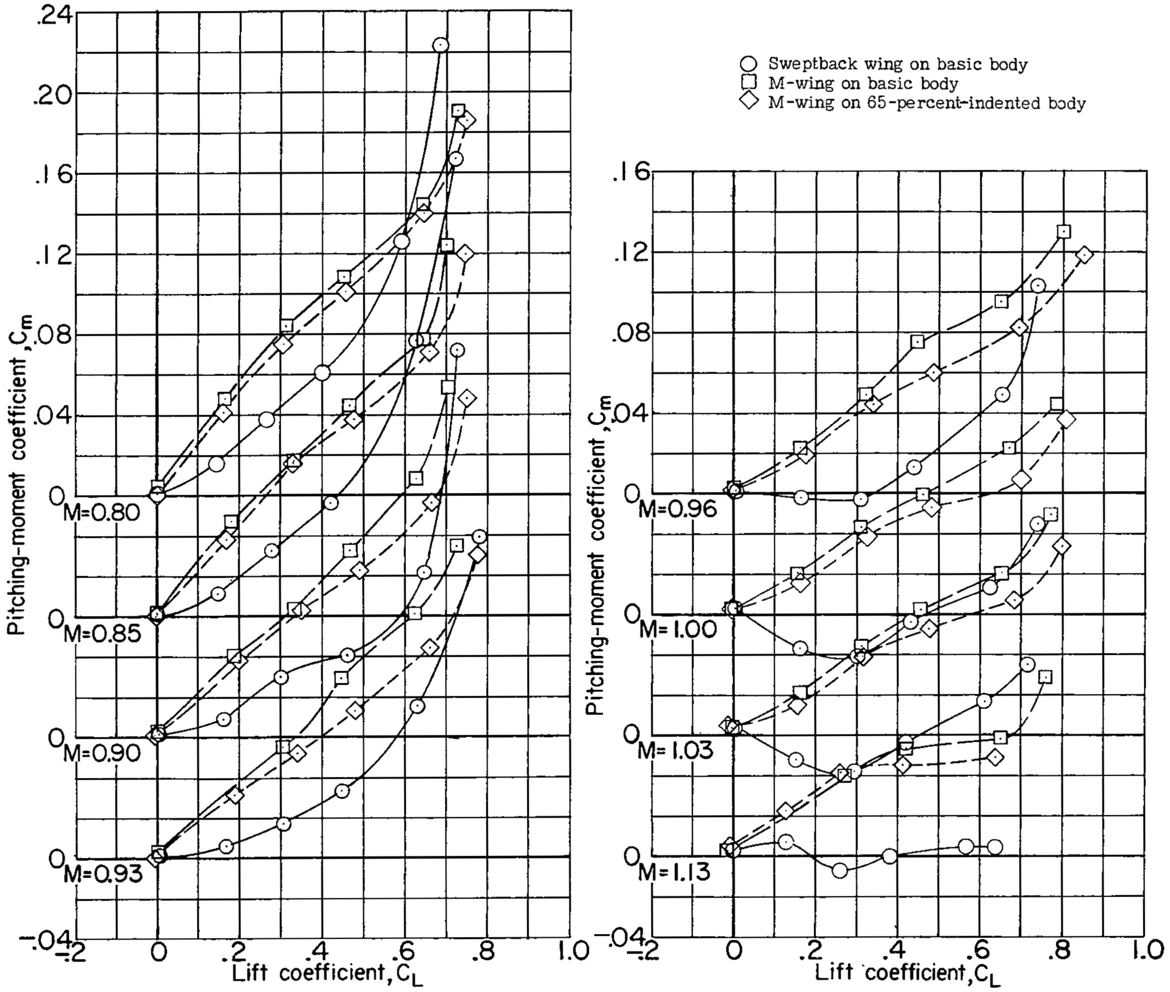

(c) C_m against C_L.

Figure 6.- Concluded.

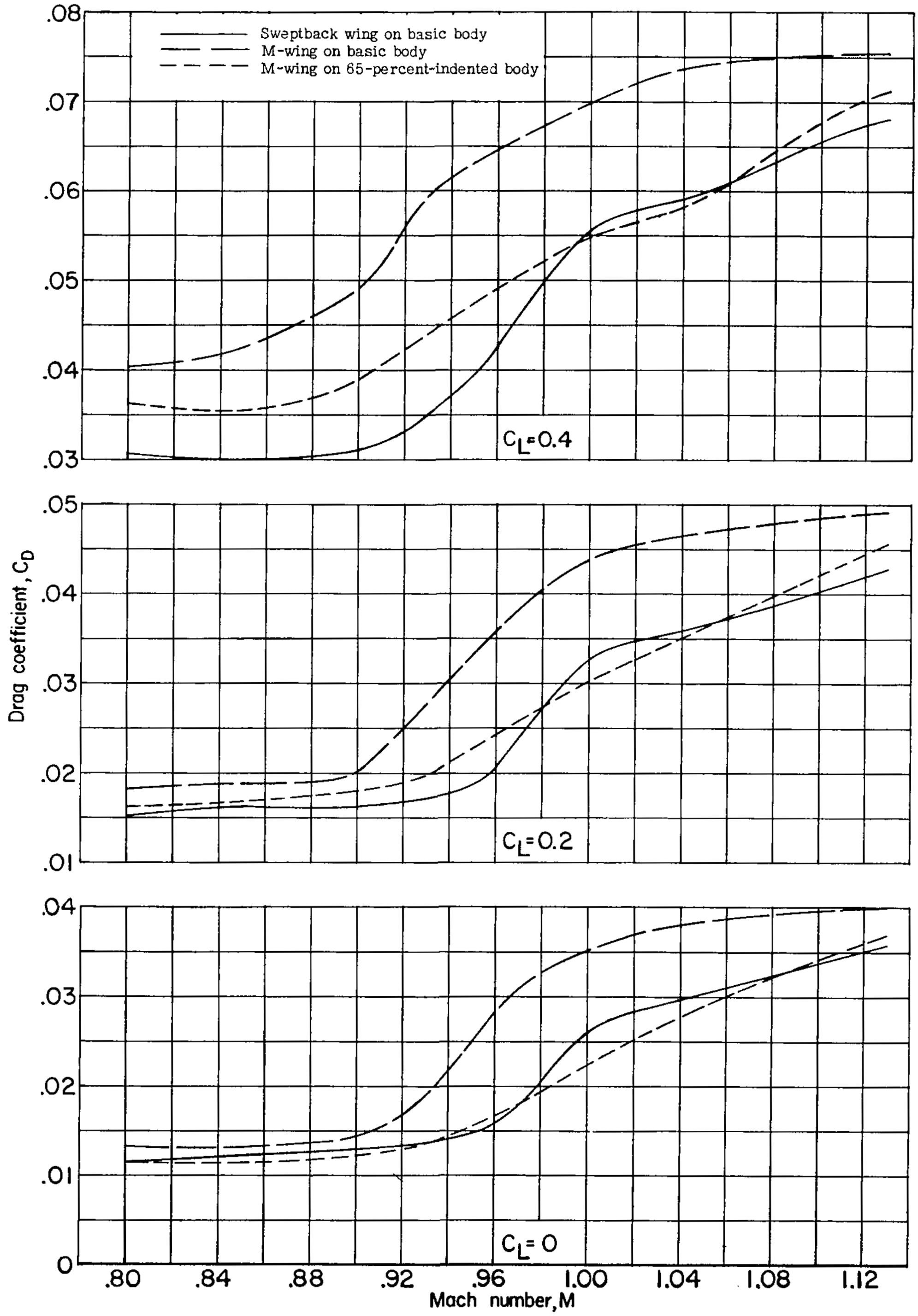

Figure 7.- Effect of body indentation and change in plan-form shape on the variation with Mach number of drag coefficient for several values of lift coefficient.

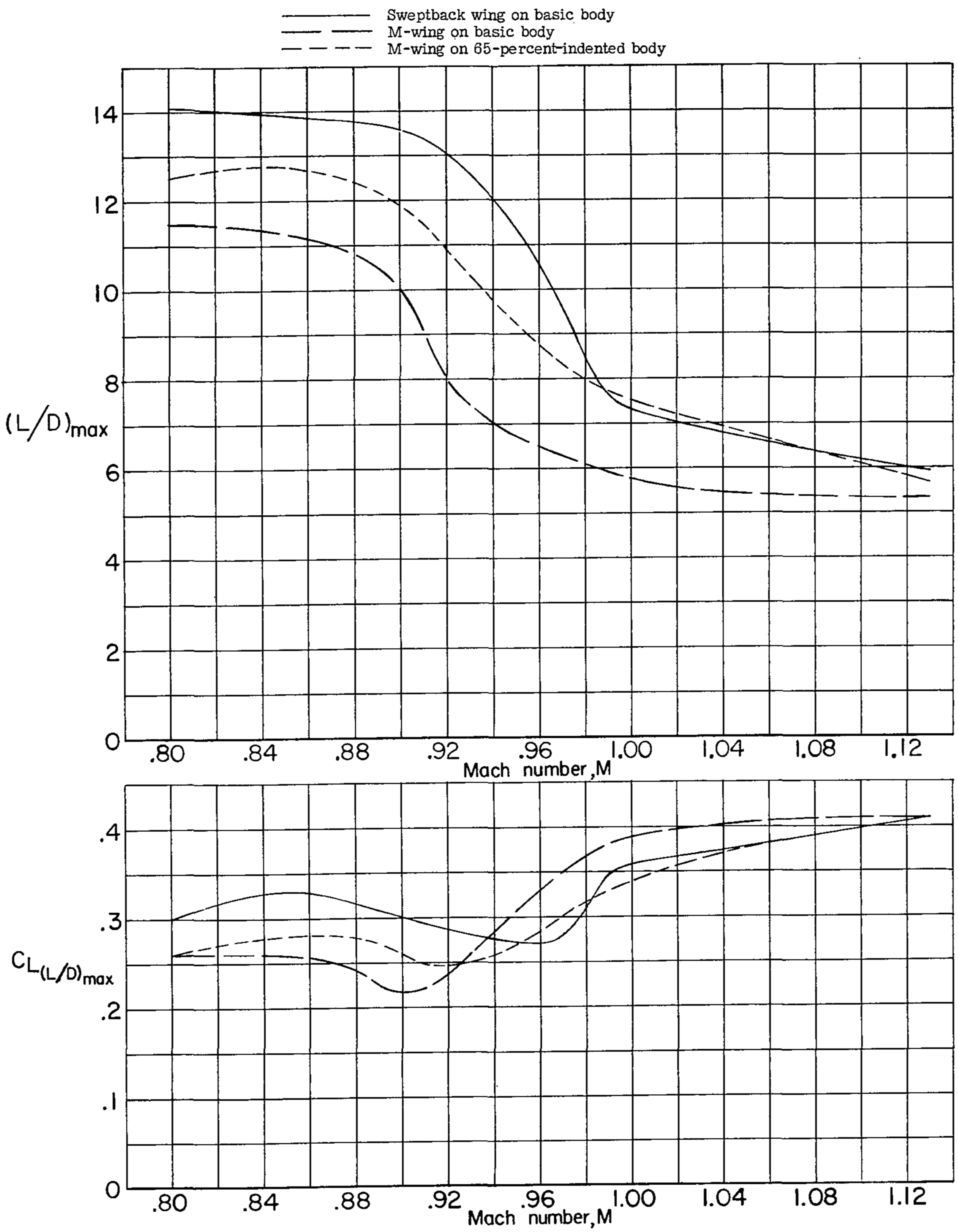

Figure 8.- Effect of body indentation and change in plan-form shape on variation with Mach number of maximum lift-drag ratio and lift coefficient for maximum lift-drag ratio.

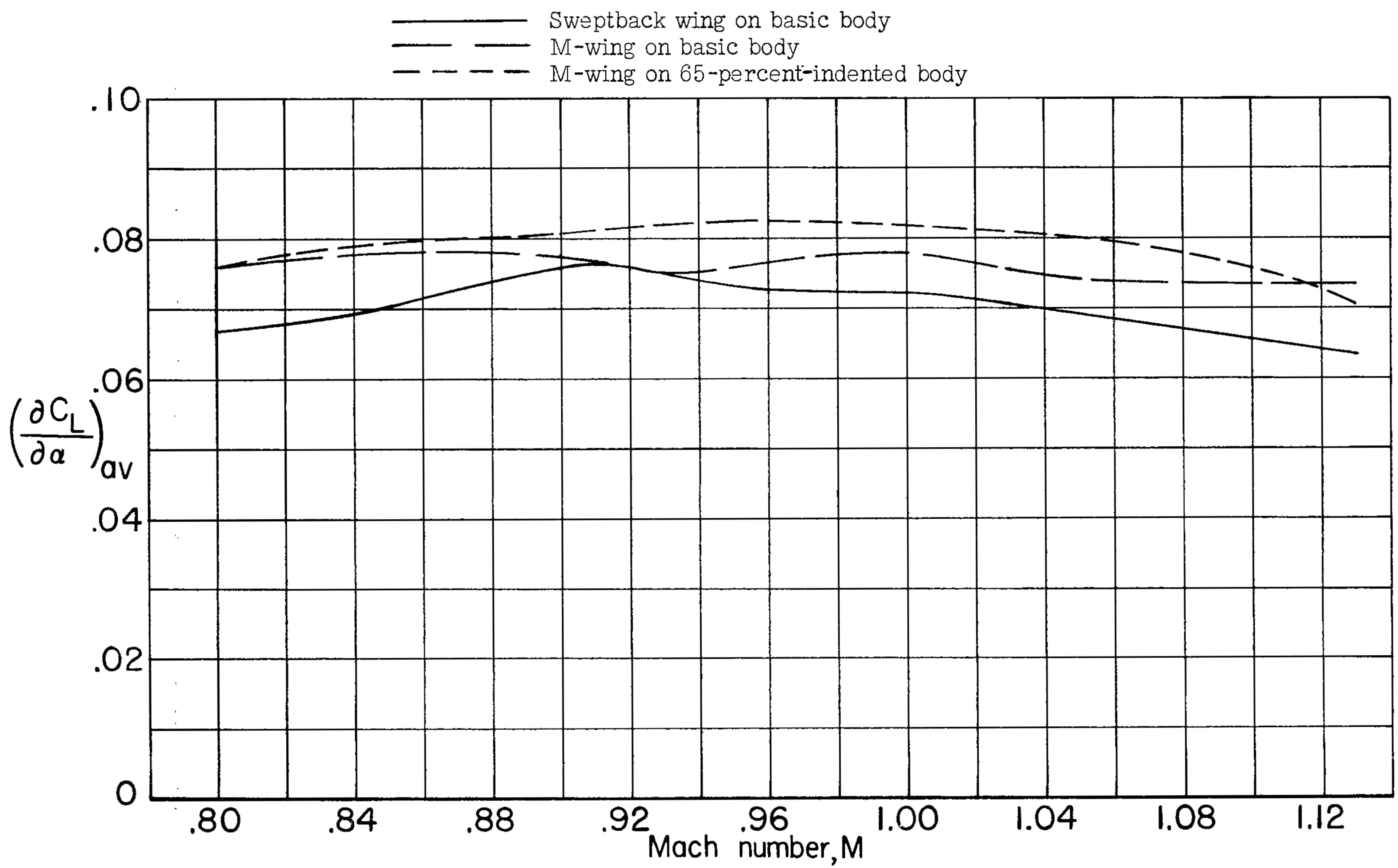

Figure 9.- Effect of body indentation and change in plan-form shape on variation with Mach number of lift-curve slope.

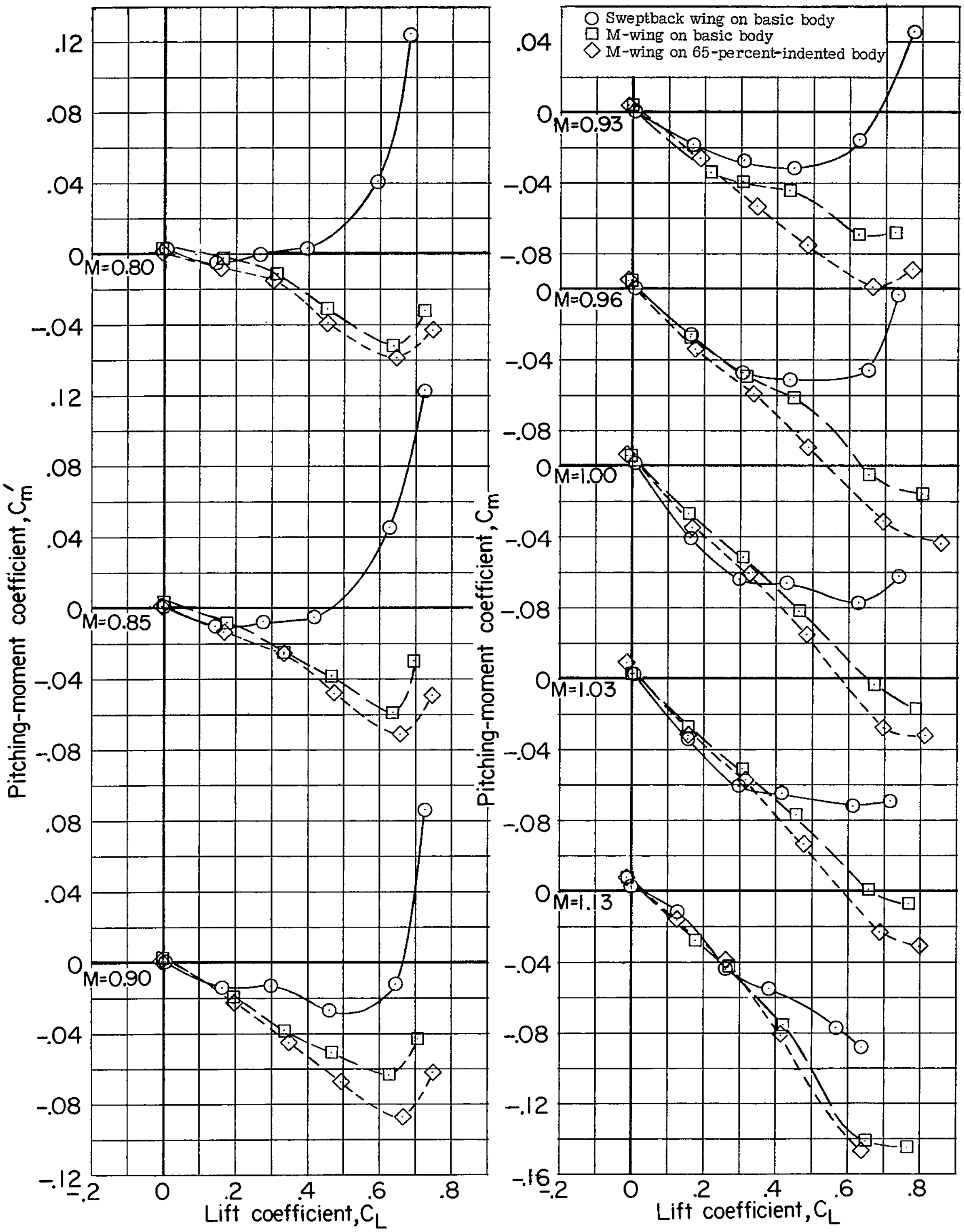

Figure 10.- Stability characteristics of the configurations investigated.

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